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The Nematode Disease

Of

Sweet Potatoes

SCAB LESION AND SWOLLEN AREAS CAUSED BY NEMATODE

THE AGRICULTURAL EXPERIMENT STATION
OF THE
NORTH CAROLINA STATE COLLEGE OF AGRICULTURE AND ENGINEERING
AND NORTH CAROLINA DEPARTMENT OF AGRICULTURE, COOPERATING
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STATE COLLEGE STATION
RALEIGH

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THE NEMATODE DISEASE OF SWEET POTATOES

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and
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The sands and sandy loam soils are the only types recommended for growing sweet potatoes. On such soils the color, shape, and size produced is of the finest quality. Potatoes grown on these soils cure, store, and are less susceptible to rots in storage and transit than those grown on heavy soils. However, these sandy soils which are so desirable for growing this crop are very largely infested with the well known and muchly investigated (1) (5) (10) (17) parasitic nematode (*Caconema radicicola* (Greef) Cobb, *Heterodera radicicola* (Greef) Muller,) which causes the big root of tobacco, tomato, okra, soybean, cow pea and many other plants in this State. It attacks and injures the vitality of a great many economic, shade and ornamental plants. The peanut, velvet bean, and Laredo soybean are resistant legumes (10). The Iron and Brabhåm varieties of cow peas are generally found to be more resistant to this disease than other varieties, but even these are sometimes severely attacked.

The resistance of strains and varieties of most plants to this disease offers a comparatively broad field of study and is a most encouraging and promising means of controlling the disease in some varieties of plants (15) (19). The sweet potato has been classed as a susceptible crop for some time (10) and nematode injury has also been noted (8). The effect of the nematode disease on different varieties of sweet potatoes is important because it greatly lowers the yield and injures the edible and market value of susceptible varieties. Some valuable results have been obtained by studying the resistance of the commercial varieties of sweet potatoes on infested soils during the past three years. The results on comparative resistance and susceptibility are conclusive and of sufficient importance to warrant publishing the information available at this time since it may be of great help to those who find it necessary to plant sweet potatoes on infested soils.

INFECTION AND DISEASE SYMPTOMS

Plants infected early in the season may sometimes show a suppression of vine growth, and at harvest the yields may be small. On the other hand late infection may not seriously affect the vine growth or the amount of the yield. Plants are not killed by the disease, nor is there any evidence of wilting or yellowing of the foliage due to the disease. The objections to the disease are poor production and wormy potatoes. The disease is not readily seen on the most resistant varieties. Resistant strains and varieties may easily be overlooked, since infection is often very unimportant and may be found only on injured tissues on some varieties. The root system of very susceptible strains and varieties is very ragged when severely attacked. The disease may cause definite scab-like lesions and slightly swollen areas on the potatoes.

Some idea of the diseased condition of the Nancy Hall sweet potato variety is shown by the following seven pictures with explanations of each. In figure 1 the knot or swollen areas on the roots and rootlets are well distributed throughout the root system. The rootlet tips killed beyond the swollen areas are prominent. On the most susceptible varieties the destruction of the rootlets is very great. The infection of the small potatoes is usually heavy during September and October as shown in figure 2. The swollen areas are localized and appear to be more scab-like than knot-like. The potatoes become infected through the lateral

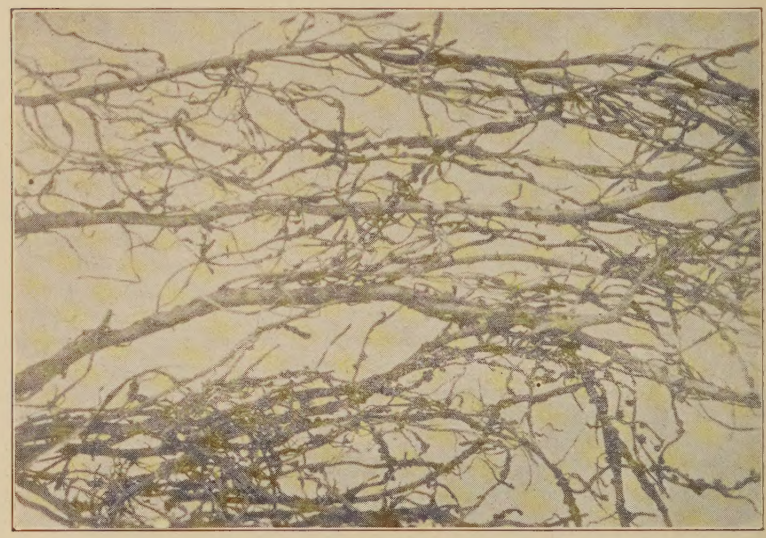

Figure 1—Swollen areas on rootlets and roots and decayed tips.

roots. This results in scab-like lesions and sunken areas, (figure 3). The female worms are sometimes abundant underneath the surface of the lesions, after following the conductive tissues inward toward the center of the potato. These scab-like lesions are sometimes enlarged in such a way that rings partly encircle the potato shown in figure 4. The worms seem able to enter the injured tissues most readily, or prefer injured to uninjured tissues, since they are most abundant on the former. Cracked potatoes of susceptible varieties are frequently heavily infected with worms and show severe worm injury, (figure 5). The female worms enter the potato to various depths, ranging from the cortex to one inch deep and appear to be fully grown at harvest the latter part of October. The brown to dark discoloration of tissues around the female worms in small potatoes, (figure 6), and large potatoes (figure 7), is prominent and very definite. The concentration of worms in the injured areas and the lightly infected uninjured areas are shown in figure 7. The maximum

swollen or raised areas are shown in figures 2 and 4. In no case have the susceptible varieties developed such large swollen tissues as are found on tobacco, tomato, and other plants of the Solanaceae.

SEED AND PLANT INFECTION

The female worm lives over winter in the seed potato. It was successfully carried over winter in potatoes in the laboratory at the College, and in storage houses on the station farm at Willard and at New Hill. It probably lives over in potatoes under any method of storage used in this State. Infected plants were developed from infected potatoes under

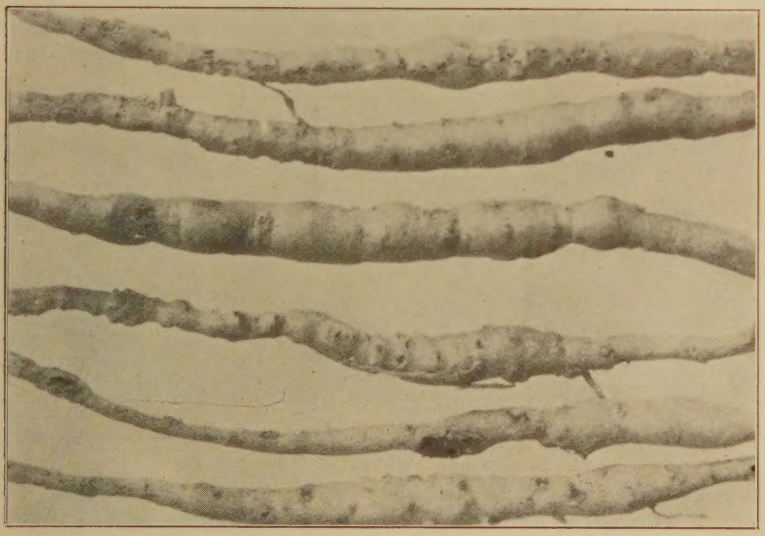

Figure 2—Small potatoes with swollen areas and scab-like lesions.

greenhouse conditions. The eggs were hatched at various periods and at the time the potatoes were bedded the small worms from infected potatoes were abundant. The infected sprouts are responsible for some spreading of the causal worms and to some extent the dissemination to new areas. It remains to be shown whether or not the worms can be repelled or killed with disinfectants. Freeing seed stock by means of disinfection will probably be difficult, since the females are sometimes imbedded deeply enough to escape the chemicals, unless the worms are killed at the time of emergence. Considering what is known about the infection at this time, it is certain that the use of infected seed or infested soils for growing sprouts would not be a good practice.

The infested soil is an excellent source of sprout infection, when the temperature and moisture conditions are favorable. The same temperature and moisture conditions are necessary for germinating the potatoes, therefore the disease will never be controlled practically by lowering

these conditions in the plant bed. Plants grown in infested soil become diseased throughout August, September, and October. The most severe period of infection was not determined, but late infections were the most important because of the injury to the edible and sale value of susceptible varieties. On the other hand heavy infection during the early part of the growing season resulted in low production.

SOIL TYPES INFESTED

Heavy soils are less favorable for the development of the nematode disease than the sandy and sandy loam soils. The warm well aerated sands of the Norfolk series are most favorable for the disease as diseased potatoes were found on the Norfolk loamy fine sand in Currituck, Brunswick, Moore, and Richmond Counties; on Norfolk fine sandy loam in Edgecombe, Wayne and Pender Counties; and on Granville fine sandy

Figure 3—Scab-like abrasions made by female worms entering through small roots and following the course of the conductive tissues.

loam in Wake and Chatham Counties during the past two seasons. The disease probably occurs on other types of sandy soils not included in this study. The infection is not always uniformly distributed on any area or farm. Heavy infection may occur in one part of the field and light or no infection in other parts. On the central station farm, there was no infection in heavy sandy loam soils on both sides of a light loamy sand in which the infection was severe. Soil conditions seem to exert a controlling factor on the disease, since neither dry nor wet soils are favorable for its development. The results of tests indicate sweet potatoes will become diseased on infested soils where other susceptible crops become diseased.

EXPERIMENTS WITH SUSCEPTIBLE AND RESISTANT VARIETIES

At various periods the Nancy Hall, Red Brazil, Southern Queen, and Norton Yam varieties have been grown in the Eastern part of this State. These varieties are now very largely replaced by the Porto Rico variety. This change is probably due to the popularity of the Porto Rico variety and to heavy nematode infection of the susceptible varieties as the Porto Rico strains and varieties have been very resistant to the disease through-

out the infested areas. They have given good yields on soils where the susceptible varieties have been a failure. There was such a wide difference in the infection of the Nancy Hall and Porto Rico varieties that resistance appeared to be a definite means of reducing losses caused by this disease and developing potatoes free from worms. Although there was a vast difference between the susceptibility of the Porto Rico and Nancy Hall varieties, no information is available on susceptible and resistance relations of other varieties.

TABLE I

THE RELATIVE SUSCEPTIBILITY OF IMPORTANT COMMERCIAL SWEET POTATOES TO NEMATODE DISEASE

Variety	Infection Per Cent	Yield per Acre, bu.	Remarks
Red Jersey	0 8	245.0	No infection of roots.
Yellow Jersey	1.0	228.0	Very slight infection, confined mostly to ends of small roots.
Big Stem Jersey	1.2	238.0	Very slight infection, confined mostly to ends of small roots.
Porto Rico	1.2	237.0	No infection of roots, but slight infection of cracked potatoes only.
Triumph	5.8	120.5	Very slight infection of roots.
Southern Queen	35.5	107.3	Uniform but slight infection of roots.
Norton Yam	85.0	71.1	All roots badly diseased.
Nancy Hall	100.0	81.7	All roots and potatoes severely diseased, roots badly broken—potatoes severely marked
Yellow Yam	100.0	28.1	All roots and potatoes severely diseased, roots badly decayed and broken, potatoes severely marked.
Red Bermuda	100 0	26.6	All roots and potatoes severely diseased, roots broken.
Pumpkin Yam	100 0	32.5	All roots and potatoes severely diseased, roots broken.

During 1926, 1927 and 1928, experiments were conducted with popular commercial and other sweet potato varieties on infested soils on the State test farm at Willard. The results obtained during 1926 are given in table 1. Potatoes of the Red Jersey, Big Stem Jersey, Yellow Jersey and Porto Rico varieties showed less than 2 per cent infection. The Red Jersey variety showed slightly less infection than other Jersey varieties. The infection of the Porto Rico was seen in the cracked areas only. There were no raised or swollen areas on the roots such as were observed on the very susceptible varieties. The root system of the Triumph variety was slightly infected, and the potatoes were diseased near the ends and in cracked areas. The root systems of the Nancy Hall, Yellow Yam, Red Bermuda and Pumpkin Yam varieties were severely infected. A large percentage of the rootlets were broken at infected points. It was not determined whether or not other organisms aided in breaking and destroying the roots, since the nematode infection was found to be the primary cause. The decay of the roots of the Red Bermuda variety was so severe that sufficient rootlets could not be removed to

get a representative photograph of the actual infection. The root and rootlet infection of the Nancy Hall shown in figure 1 is therefore, not the most severe type.

A percentage estimate of the degree of infection of individual potatoes was abandoned because infected areas overlap and rootlets of the very susceptible varieties broke off in the soil and were lost. The percentages of infection were obtained by estimating the number of diseased potatoes. Results obtained in this way are not altogether satisfactory because the actual 100 per cent infection of both the Red Bermuda and Nancy Hall varieties may indicate equal susceptibility. However, the infected conditions of the Red Bermuda was much more severe than that of the Nancy Hall. This is readily shown in the low yield of 26.6 bushels per acre produced by the Red Bermuda variety. The Nancy Hall produced 55.1 bushels per acre more than the Red Bermuda. On the other hand the Porto Rico produced 155.3 bushels per acre more than the Nancy Hall. The potatoes of the Nancy Hall and Red Bermuda

Figure 4—Scab and ring-like lesions and swollen areas made above the female worms.

varieties were of low value, due to the abundance of female worms imbedded in the inner tissues. The strains related to Porto Rico and known as New Gem and Dixie Yam were as resistant and as productive as the Porto Rico on infested soils. The General Grant and Myers early varieties related to the Nancy Hall were severely attacked. The White Yam and Miles Yam varieties gave similar results to the related Southern Queen variety.

The same varieties used during 1926 were planted on the same infested soil area again in 1927. The test was repeated in an adjoining field. The data obtained in both tests are similar. Therefore, the results from the first field only are given in table 2. The infection during 1927 was not as early nor as severe as during the 1926 season. The late infection did not affect the yield of susceptible varieties as much as it did during the previous season. It did however result in an abundance of female worms entering the potatoes.

Of the thirty varieties or related strains tested, fourteen showed high resistance. The Gold Skin, Yellow Jersey, Red Jersey, Big Stem Jersey, Yellow Jersey Vineless, Old Long Red Jersey, Porto Rico, New Gem, Golden Porto Rico, Dixie Yam, Creola, Japan Brown Sweet, Enormous and Triumph varieties were resistant. Pumpkin Spanish, Miles Yam, Southern Queen, White Yam, Yellow Yam, Norton Yam and Short Horn

TABLE II

THE RESULTS OF TESTING SWEET POTATO VARIETIES ON NEMATODE INFESTED SOIL ON TEST FARM, WILLARD, N. C.

Variety	Infection Per Cent	Yield per Acre, bu.	Remarks Concerning Infection
Gold Skin Jersey	0 2	234.4	Very slight infection of potatoes.
Yellow Jersey	.5	267.6	Slight rootlet infection, few scab-like lesions on potatoes.
Red Jersey	.5	211.2	Slight infection of roots.
Big Stem Jersey	.6	311.2	Both root and potato slightly diseased.
Yellow Jersey Vineless	.9	260.6	Rootlet tips slightly infected.
Old Long Red	1.2	286.3	Scab-like lesions on few potatoes. Infection of rootlet tips.
Porto Rico	1.8	405.3	Slight infection of rootlets and cracked potatoes.
New Gem	2.1	475.4	Roots slightly diseased.
Golden Porto Rico	2.1	201.4	Potatoes slightly infected through cracks and lenticels.
Dixie Yam	2.3	452.3	Potatoes slightly scabbed, and rootlets infected at tips.
Creola	3.0	570.8	Potatoes infected in cracks and lenticels.
Japan Brown Sweet	3.0	444 9	Scabbing of potato and infection of rootlet tips.
Enormous	3.5	415.2	Roots and potatoes slightly infected.
Triumph	8.9	239.9	Roots and potatoes infected.
Pumpkin Spanish	30.5	195.7	Scab lesions prominent on potatoes.
Miles Yam	38.0	270.3	Scab lesions abundant on potatoes.
Southern Queen	45.0	376.0	Slight infection of roots. Potatoes scabbed.
White Yam	45.0	297.8	Slight infection of roots. Potatoes scabbed.
Yellow Yam	53.0	235.2	Severe root infection. Moderate infection potatoes.
Norton Yam	65.0	246.6	Scab lesions severe on potato.
Short Horn	65.0	305.3	Scab lesions severe on potato.
Myers Early	100.0	225.6	Potatoes scabbed. Roots infected.
Vineless Yam	100.0	115.1	Roots and potatoes heavily infected.
Belmont	100.0	80.2	Roots and potatoes heavily infected.
Pumpkin Yam	100.0	165.5	Roots and potatoes heavily infected.
Jewel Yam	100.0	253.7	Roots and potatoes heavily infected.
Pierson	100.0	184.0	Roots and potatoes heavily infected.
General Grant Vineless	100.0	256.1	Potatoes scabbed, roots severely infected.
Nancy Hall	100.0	215.6	Potatoes scabbed and heavily infected at tips.
Red Bermuda	100 0	138.1	Potatoes severely scabbed and infected.

varieties were badly infected but not to the same extent as Myers Early, Vineless Yam, Belmont, Pumpkin Yam, Jewel Yam, Pierson, General Grant Vineless, Nancy Hall, Red Bermuda and Red Brazil varieties. Under remarks concerning infection, the relation of the disease to root-

lets, roots and potatoes is explained for each variety. Some varieties were severely scabbed. Others showed greater rootlet and root infection. The roots and rootlets of all varieties showing 100 per cent potato infection were heavily infected. Some varieties showed more broken rootlet tips than others, but the female worms were always abundant in the root tissues as well as in the potatoes, especially in the end farthest from the stem. When resistant varieties were attacked, infection was mostly through the injured tissues, especially on surfaces cracked as a result of water and temperature changes in the soil during the growing season. A microscopical examination of the injured tissues indicated that

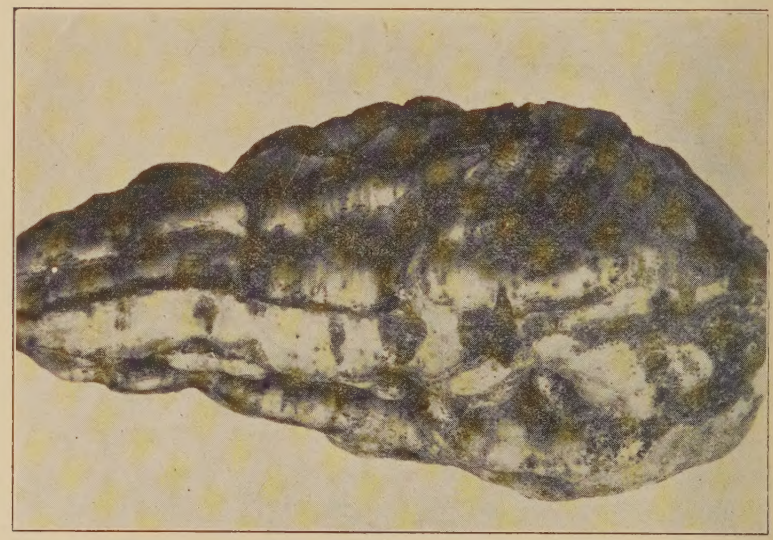

Figure 5—Cracked potato showing tissues heavily infected with worms.

the worms had worked in the substances from the broken cells without entering the potato.

In considering the comparative yields of a large number of varieties on any soil type full allowance must be given for any natural variance that might be caused by conditions other than nematodes. However the Nancy Hall, Porto Rico, Red Bermuda, Red Jersey and Southern Queen varieties produce uniform yields, except on infested soils. The Jersey varieties produce a very high percentage of salable potatoes. Although the total weight or production of these varieties is nearly always less than that of the Southern types. The Porto Rico, Enormous, Dixie Yam, Southern Queen, New Gem, Creola, and Japan Brown Sweet may produce a total of 100 bushels per acre more than the Jersey varieties but still not equal them in total quality of salable potatoes. There is a tendency for the Southern types to produce large potatoes and others of a rooty condition which give weight but poor value. The total produc-

tion is given here because the large yields do indicate a rather definite degree of resistance.

During 1928, tests were made with susceptible and resistant varieties on the same soil at the branch station farm at Willard, on the central station farm and on the branch station farm near Rocky Mount. In all of these tests the best methods of culture were followed. The test plantings of each variety were repeated so that more than 100 plants were used. The results were so similar to those obtained the two previous seasons that it will not be necessary to give them further discussion. However, the results obtained on the central station farm are given in table 3 to show the very wide differences in yield obtained on infested soil. The production of the Nancy Hall and Red Brazil varieties was greatly reduced and the potatoes were all badly infected with female worms. The Porto Rico and Red Jersey varieties produced 201 and 106.5 bushels more per acre respectively than the Nancy Hall variety. The Nancy Hall variety produced 57.9 bushels per acre more than the Red Brazil. The Red Bermuda variety was so severely infected on the test farm at Willard that the total yield was only eight bushels per acre. It is the most susceptible variety studied thus far. The Big Stem Jersey variety was found to be more severely diseased at Currituck Court House than was observed in the test areas. The ends of some potatoes and the roots and rootlets were both diseased. Roots and potatoes of the Porto Rico variety sent by R. C. Thomas from the Experiment Station at Tifton, Georgia, showed slightly greater infection than was observed in this State.

TABLE III

RESULTS OF TESTING SWEET POTATO VARIETIES ON NEMATODE INFESTED SOILS ON CENTRAL FARM

Variety	Potato Infection Per Cent	Yield per Acre, bu.	Remarks on Infection
Red Jersey	0	215.0	Slight infection rootlet tips only.
Yellow Jersey	0	205.0	Slight infection of rootlet.
Porto Rico	1.0	309.5	Slight infection rootlet and cracked potatoes.
Triumph	10.5	195.3	Moderate infection of rootlets.
White Yam	38.6	253.5	Moderate infection of rootlets.
Yellow Yam	41.2	175.1	Moderate infection rootlets. Scab markings on potato.
Nancy Hall	100	108.5	Severe infection of rootlets and potatoes.
Red Brazil	100	50.6	Severe infection of rootlets

RESISTANCE STUDIES

The cause of resistance is not known. There seems to be no relation of the physical characters to resistance. It is not influenced by vigor of growth, because the Red Brazil, White Yam and Yellow Yam varieties are equal to the resistant Porto Rico in growth of vines and production in soils not infested with nematodes. There is no color pigment relation, since the Red Jersey is highly resistant and the Red Bermuda very susceptible. The same thing is true of Yellow varieties. Furthermore, the

so-called dry or firm textured and moist or less firm textured types are equally susceptible. The Yellow and Red Jersey dry types and the Porto Rico, a moist type, are about of equal resistance. On the other hand the Red Brázil, a dry type, and Nancy Hall, a moist type, are both very susceptible. The abundance and largeness of the root system seemed to be of no relation to infection, since the Yellow Jersey produces many fibrous rootlets and the Porto Rico very few. This is also true of the susceptible varieties. The thickness of the cortex of the different varieties is certainly of no great importance because the worms were more severe on cracked areas of Nancy Hall, Red Bermuda, Red Brazil and other susceptible varieties than on similar areas of the resistant Porto

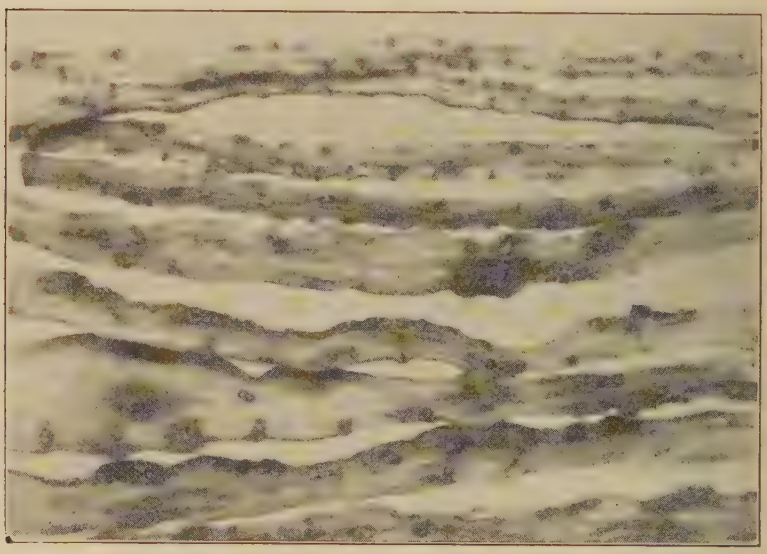

Figure 6—Section through small potatoes showing female worms and brown and discolored tissues around the worms which appear white in the tissues.

Rico and Jersey varieties. The close relation of a chemical analysis of varieties, inorganically speaking, would seem of no importance, however, the nema attraction to some varieties and not to others will probably be explained by a more thorough analysis of organic and inorganic compounds than is now available.

DISCUSSION

This paper points out the comparative resistance and susceptibility of important commercial and other sweet potato varieties to the nematode disease. The results are based upon tests conducted for three consecutive years on the same infested soil. During this period, there was no evidence to show that any variety became more susceptible or more resistant after growing for three consecutive years on the same soil. The actual cause of resistance is not known. The physical characters seem to bear no relation to resistance.

The resistant Porto Rico and Jersey varieties are the most popular varieties grown throughout the Eastern part of this State. The susceptible Nancy Hall, Norton Yam, Red Brazil, and Southern Queen varieties are grown in local areas, but not to the same extent as the Porto Rico and Jersey varieties.

Not all sandy soils are infested. On the test farm at Willard, the susceptible varieties were not attacked on an area used for growing the commercial crop. The female worms live over winter in the potato which is probably of less importance as a source of infection than the infested soils. The development of sprouts in infested soil and the use of diseased seed potatoes are means of spreading and disseminating the worms to

Figure 7—Sliced sweet potato showing heavy infection in the cracked areas and the female worms at different depths in the tissues.

new areas. Whether this has had much bearing on the present wide distribution of the nema is not known. Other susceptible crops such as tomato and tobacco, which are grown in plant beds and transplanted in these same soils, are also responsible for disseminating the worm. The plow is probably responsible for spreading the worm from infested to uninfested areas.

Sweet potatoes are generally considered to be an excellent crop to rotate with tobacco, but where the soil is infested, a rotation of these crops, even when the most resistant varieties of sweet potatoes are used, would not reduce the number of worms. It would have a tendency to increase the soil infestation.

Perishing the worms on infested areas as is proposed by Godfrey (10) is probably not a practical means of control on any farm in this State. Extremely clean cultivation and the use of an immune crop would be in order as a possible means of reducing the worms. Rye, corn and

peanuts are about the only immune crops that do well on the light sands. Where the worms are now causing severe damage a change could be made to one or more of these crops, since they would probably give greater returns than very susceptible crops on infested soils.

The low yields of susceptible sweet potato varieties on infested soils is certainly of less importance than the infection of the potatoes by female worms. A large percentage of the worms remain in the vicinity of the cortex mostly in the necrotic areas just beneath the surface and would be removed if the potatoes are peeled. Some of the worms are more deeply imbedded in the tissues and extra cutting would be necessary to remove them. The amount of wastage would always be important.

The sweet potato becomes infected severely the first year on infested soil. The test conducted on the central farm is the first record of sweet potatoes on the area used, and the infection results were equally as great as those obtained after growing the same varieties for three consecutive years on the same area at Willard.

In studying the nematode disease in storage and in the field, no evidence of its relation to other diseases was determined. A small percentage of the plants were affected with the wilt, but in storage the nematode infected potatoes kept as well as those which were not attacked.

Abandoning infested soils is a questionable means of control, because there are so many susceptible weeds and trees that would help maintain the soil infestation.

When it is difficult to obtain uninfested soil for the plant bed, a hot water treatment for control is suggested. (3) (4) (20). Steam is another method of killing the worms in plant beds (13). The root knot is also affected by calcium cyanamide (18) but this method is still in the experimental stage. In plant beds the worms are not active at low temperatures, (9) (11) but this method of control could not be applied in plant beds because a temperature above that at which infection takes place is necessary for germinating and developing sprouts. The use of predatory nematodes has been suggested and may eventually prove very beneficial for controlling this disease (6) (16). Various other measures for the control of the nematode have been proposed and investigated (2) (7) (12) (14) and (17), but all of these methods involve extra expense. They are applicable to certain crops. The wide degree of selection among the highly resistant varieties and strains makes varietal resistance a most economical measure for controlling this disease of sweet potatoes.

SUMMARY

The nematode, nema, big root, root knot, or eel worm disease caused by a well known worm, *Heterodera* (*Caconema*) *radicicola* attacks a large percentage of the economic plants of this State.

The sweet potato is attacked and the symptoms and results are small swollen areas on rootlets, roots, and potatoes, scab-like lesions, ring-like lesions, broken rootlets, slightly darkened tissues, wormy potatoes and sometimes a reduction of growth and yield.

The warm well aerated Norfolk series of soils are most suitable for the development of the disease. The Granville fine sandy loam and probably other sandy soils are infested.

A severe infection of the sweet potato plant early in the season reduces yields. Late infection affects the edible and market quality of the potato, because of the presence of the female worms in the tissues.

The female worm lives over winter in the potato under the storage methods practiced in this State. Sprouts become infected from infected potatoes and from infested soils. Disseminating and spreading of the worms may be readily done with the diseased plants.

The sweet potato varieties tested for three consecutive years on the same infested soil showed wide variation in resistance and susceptibility. The Jersey and Porto Rico varieties and strains were highly resistant. The Nancy Hall, White Yam, Southern Queen, Red Bermuda, Red Brazil and Norton Yam varieties and strains were susceptible.

The physical characters such as growth vigor, root production, thickness of cortex, pigmentation, and firmness of texture seem to bear no relation to resistance.

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